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Project: Real Time Carbon Storage Monitoring Pipeline with BigQuery

Overview

This project demonstrates how I designed and deployed a real time Carbon Capture and Storage (CCS) data streaming pipeline on Google Cloud. The system ingests live sensor data from CO₂ injection wells, processes it continuously, and stores it in BigQuery for immediate querying and analysis.

Rather than relying on batch uploads or manual reporting, this architecture supports continuous CCS sensor data, making it suitable for use cases such as injection monitoring, storage integrity oversight, and operational analytics for safe long term carbon storage.

Problem Statement

Oil field engineers supporting CCS operations needed a solution to:

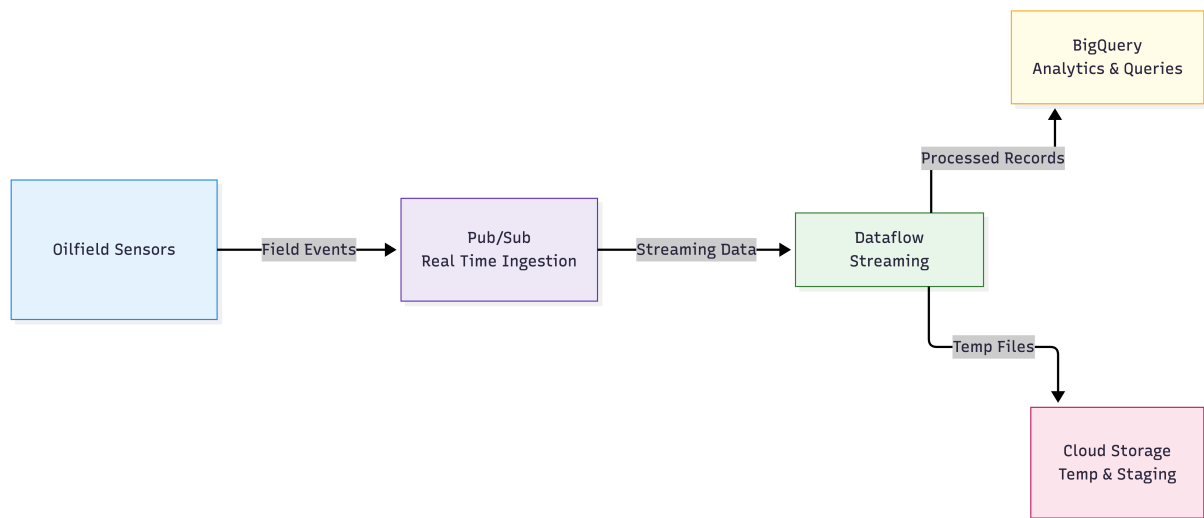
- + Ingest real time sensor data from CO₂ injection wells
- + Process continuous pressure and temperature data reliably at scale
- + Store CCS sensor data in an analytics ready data warehouse
- + Validate incoming field data as it arrives

Goal: Responsible for designing and implementing the end to end CCS sensor data streaming pipeline using Google Cloud managed services.

Tech Stack

- + Cloud Storage – temporary and staging storage for Dataflow job execution
- + Pub/Sub – real time ingestion of oilfield sensor data
- + Dataflow – continuous stream processing of field data
- + BigQuery – analytics storage for querying and validation

Architecture Overview



Flow of Data

1. CO₂ injection well sensors publish sensor data events
2. Pub/Sub ingests CCS sensor data in real time
3. Dataflow processes the sensor data stream continuously
4. BigQuery stores processed records for analytics and reporting
5. SQL queries are used to validate data and analyze injection conditions

This architecture is serverless, scalable, and aligned with modern digital oilfield platforms.

Deployment Steps

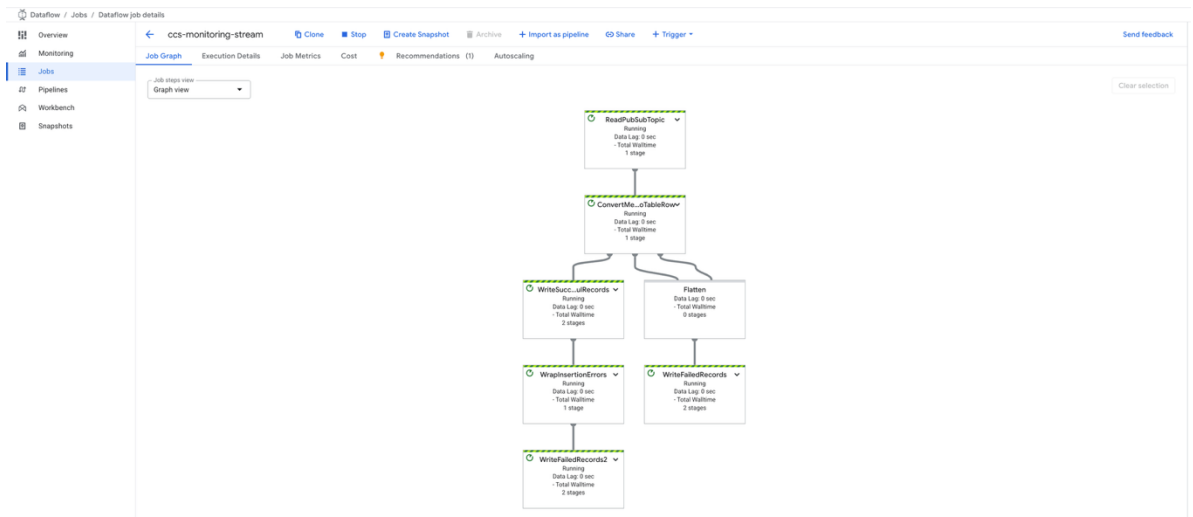
- + **Provisioned Cloud Storage for Dataflow execution job**
- + **Created a BigQuery dataset and table for streaming ingestion**

The screenshot shows the BigQuery 'Schema' view for a dataset named 'co2_injection_telemetry'. The table has the following columns:

Field name	Type	Mode	Description	Key	Collation	Default Value	Policy Tags	Data Policies
storage_site	STRING	NULLABLE	-	-	-	-	-	-
injection_well	STRING	NULLABLE	-	-	-	-	-	-
co2_injection_temperature_f	FLOAT	NULLABLE	-	-	-	-	-	-
co2_injection_pressure_psi	FLOAT	NULLABLE	-	-	-	-	-	-
co2_injection_rate_tpd	FLOAT	NULLABLE	-	-	-	-	-	-
timestamp	TIMESTAMP	NULLABLE	-	-	-	-	-	-

At the bottom, there are buttons for 'Edit schema' and 'View row access policies'.

+ Configured Pub/Sub for real time oilfield sensor data ingestion



+ Deployed a Dataflow streaming pipeline from Pub/Sub to BigQuery

```
JOB ID: 2026-01-08_19_05_35-14579305350506963036
NAME: iotflow
TYPE: Streaming
CREATION_TIME: 2026-01-09 03:05:36
STATE: Running
REGION: us-central1
```

Overview

Monitoring

Jobs

Pipelines

Workbench

Snapshots

Jobs

Create Job From Template

Create Job From Builder

Filter Filter jobs

Enable sorting

Refresh

Manage

Learn

Running

Archived

Name

Type

End time

Elapsed time

Start time

Status

SDK version

ID

Region

Insights

ccs-monitoring-stream

Streaming

Jan 11, 2026, 5:59:01 AM

1 min 7 sec

Jan 11, 2026, 6:02:57 AM

Running

2.69.0

2026-01-11_01_32_56-11532884719047441522

us-central1

1 Insight

ccs-monitoring-stream

Streaming

Jan 11, 2026, 5:59:01 AM

3 sec

Jan 11, 2026, 5:58:58 AM

Failed

2.69.0

2026-01-11_01_28_57-17473628174562964109

us-central1

+ Published sensor data events and validated live ingestion using BigQuery queries

```
do
  gcloud pubsub topics publish $TOPIC_NAME \
  --message="{
    \"data\": {
      \"storage_site\": \"Hibernia CCS\",
      \"injection_well\": \"INJ_${(RANDOM % 10)}\",
      \"co2_injection_temperature_f\": ${((90 + RANDOM % 60))},
      \"co2_injection_pressure_psi\": ${((2000 + RANDOM % 1500))},
      \"co2_injection_rate_tpd\": ${((500 + RANDOM % 2000))},
      \"timestamp\": \"$(date -u +%Y-%m-%dT%H:%M:%SZ)\"
    }
  }"
done
messageIds:
- '17725029986365256'
messageIds:
```

co2_injection_telemetry						
Schema	Details	Preview	Table Explorer	Insights	Lineage	Data Profile
Preview may not show all data being streamed to BigQuery. If you want to check for such data, run a SELECT statement over the table.						
Row	storage_site	injection_well	co2_injection...	co2_injection...	co2_injection...	timestamp
1	Hibernia_CCS	INJ_03	121.4	2950.0	1800.0	2026-01-08 15:20:00 UTC
2	TEST_CONFIRM	INJ_99	111.0	2700.0	1300.0	2026-01-11 10:00:00 UTC
3	Hibernia_CCS	INJ_1	103.0	2535.0	1370.0	2026-01-11 10:05:59 UTC
4	Hibernia_CCS	INJ_2	102.0	2647.0	1317.0	2026-01-11 10:06:01 UTC
5	Hibernia_CCS	INJ_3	117.0	2563.0	1217.0	2026-01-11 10:06:04 UTC
6	Hibernia_CCS	INJ_4	106.0	2564.0	1382.0	2026-01-11 10:06:06 UTC
7	Hibernia_CCS	INJ_5	106.0	2604.0	1289.0	2026-01-11 10:06:08 UTC

Each component was created in the correct region with required APIs enabled to reflect production best practices.

Outcome

- + A fully operational real time oilfield sensor data streaming pipeline.
- + Live sensor data flowing continuously from Pub/Sub into BigQuery.
- + A reproducible, cloud native analytics architecture suitable for oil and gas operations.

This project shows that I can design, deploy, and operate real time oilfield data pipelines, troubleshoot distributed cloud systems independently, and think end to end like a cloud engineer supporting energy and production environments.

By Ikenna Anasieze